

Development of Distributed Manufacturing Systems (DMS) concept

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Abstract:

Nowadays, Manufacturing enterprises in mature economies are facing a challenge how to grow on the long-term, while coping with the increasing competitive pressure of low-labour cost countries. To achieve a long-term success, manufacturers have to effectively and efficiently meet both policy makers constraints and the customers requirement, those are asking for a more environmentally and social sustainable production. Distributed Manufacturing Systems (DMS) appear to be as one of the possible answer. Consequently, they are gaining more and more attention among academic debates as well as in the manufacturing world. A multitude of models with different peculiarities have been proposed under this denomination throughout the last decades, thus resulting in an increased confusion about the concept of DMS. For this reason, this paper aims at identifying the evolution of the DMS concept by applying a systematic literature review and classification of different DMS framework presented in the scientific literature. From this study emerges that DMS models evolved from the 80s, where they were identified as a decentralized form of production control, to 00s, where they have been identified alternatively as a geographical distributed manufacturing systems and as an enterprises network.

Keywords: Manufacturing, Distributed Manufacturing Systems, Literature review.

1.Introduction

Manufacturing enterprises in mature economies are facing a challenge how to grow on the long-term, while providing high quality jobs within a much stricter legislative environment than some of their peer countries. Policymakers and the customers are asking for products more and more environmentally and social sustainable [0,1]. At the same time, the degree of customization requested and the demand for a higher involvement in product designing is constantly growing [2].

Therefore, a manufacturing company has to be able to easily and quickly expand and contract its infrastructure for staying competitive and surviving through the competitive pressure in modern business. Coherently, manufacturing systems have to be extremely adaptable and easily reconfigurable, with a high involvement of modularity principle and lower permanent investment in production facilities.

In this context, Distributed Manufacturing Systems (DMS) are gaining more and more attention among academic debates as well as in the manufacturing world [3]. Even though first traces of decentralised manufacturing systems come from the 80s, only in the last years this production schema is rapidly spreading. DMS is expected to become the main production paradigm in the future years, as indicated by World Economic Forum in the 2015 Meta-Council on Emerging Technologies [4].

This is mainly due to two enabling technology development: ICT technologies, i.e. Internet of Things and Cloud technologies, and additive manufacturing, i.e. 3D printing.

Indeed DMS is supposed to be a paradigm “greener” if compared against a large-scale centralized manufacturing and able to ensure a high degree of the product personalization [6]. It is also seen as possible mean for the implementation of the re-shoring phenomenon in Western Economies, thus increasing the interest of policymakers [7,8]. DMS allow also a broader diversity and personalization even in objects that are today standardized, such as smartphones, thus spreading product customization in other sectors.

As a multitude of models have been proposed under this denomination throughout the last decades, DMS peculiarities have changed along with technological and developments.

For this reason, this paper aims at identifying the evolution of the DMS concept. To do that, author applied a systematic literature review and classification of different DMS framework presented in the scientific literature.

2.Methodology

For the systematic literature analysis and review in this paper, the author searched on two scientific databases:

- Google Scholar(<https://scholar.google.it/>)
- Scopus (<http://www.scopus.com/>)

In particular, on Scopus database, the author has decided to apply two exclusion criteria:

- The research has been restricted to those articles with the keyword searched in their Title, Abstract or Keywords list;
- The subject areas considered have been "Engineering", "Computer Science", "Decision Sciences", "Mathematics", "Business, Management and Accounting".

In the first stage, the author has used generic keywords, i.e. "Distributed manufacturing", "Distributed production" and "Networked manufacturing", which brought to a excessive number of documents, the most part of which out of scope).

In the second step the author has used well-defined keywords for better focusing the literature analysis and thus identifying those articles more related with the research topic. Abstracts have been carefully analysed for identify the most appropriate and meaningful document for the research. Those articles have been integrally (i.e. abstract, keywords, full text) read and reviewed.

Hence, this state of the art review has been expanded by looking at references and authors of the most significant articles. In particular a limited number of authors results of great relevance for the analysis.

3. Distributed Manufacturing systems: concepts

By reviewing academic literature, it is immediately clear that different meanings have been associated to "distribution" within a manufacturing context. The results showed an evolution and a broadening of this concept, which evolved from a decentralized form of production control to a form of manufacturing systems involving several enterprises (Fig.1).

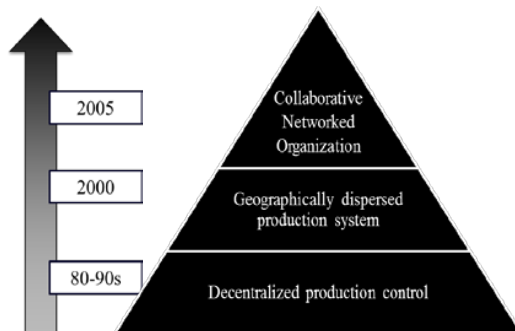


Figure 1: DMS concept evolution

3.1 Decentralized Production Control

At the very beginning (80s-90s), distribution has been related with the production control systems. For instance, Rana & Taneja in 1988 "[...] *embedded distributed real-time processing system comprised of heterogeneous components*" for controlling a shop-floor with a cellular layout where the "distribution" was incorporated into the architecture of the control system [9]. In this first stage, researches coping with the

"distributed manufacturing systems" aimed at identifying innovative architecture for the shop-floor control overcoming previous centralized architecture. At that stage, the majority of studies focused on those enabling systems, like CIM and innovative manufacturing software, for ensuring an effective real-time management of the information coming from the single production cells within the factory [10,11].

Barekat, in 1991 adopted a different viewpoint by focusing on how distributed control system affected manufacturing performances. In particular, he concluded that this control architecture brought to a reduction of the lead time in a production system with several units realizing specific products and managing autonomously its own operations (e.g. machinery loading, inventory management) [12].

3.2 Geographically dispersed production system

Later, as ICT technologies have improved and global logistics cost has decreased, enterprises started to organize their production in local geographically dispersed units.

In this context, distributed manufacturing systems have been presented as decentralised solutions for the production facilities location problem. The novelty against the previous concept of distributed manufacturing systems lied in the geographical dispersion of the production system facilities. According with this concept a production system was in separate units located in different regions all around the world.

DiDomenico, Kartika & Sibeck by comparing production strategies of the major players of the Personal Computer industry, presented Acer "distributed manufacturing" strategy. Indeed, this firm decided to perform assembly microcomputer sub-components closer to the point of sale in order to reduce inventory and the overall warehousing cost [13].

In 2004 Buckley & Ghauri, (Fig.2) in what they called "global factory", presented a distributed production system based on local production unit with identical layout and local supply chain. In this model, at central level, remains activities such as product design and engineering as well as marketing, while the local unit together with their local supplier performs the totality of the manufacturing activities [14].

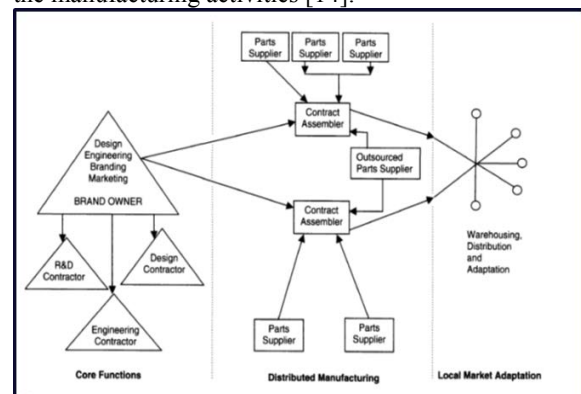


Figure 2 Global Factory, Buckley & Ghauri, 2004

In 2005 Reichwald, R., Stotko, C. M., & Piller, F. T proposed a similar concept based on Mini-factory, which they defined "[...] a designed scalable, modular, geographically distributed unit that is networked with other units of this type" [15].

Each Mini-factory was designed in a modular way, which means that each local unit is composed of modules that can be easily combined together thanks to their standard interfaces. These units reveals a high "trafosmability" thanks their modularity and their short *and local supply chain* indicates the tactical ability of an entire factory structure to switch to another product family, i.e. the "ability of an entire factory to switch to another product family trough structural interventions in the production and logistics systems" [16].

These units can be installed near to the customers, i.e. in a high customer density area such as urban context, for increasing the purchase repetition and the customer retention rate. Basically, a Mini-factory differs from a "manufacturing unit" due to the fact that it carries out a larger spectrum of operations. Indeed, each Mini-factory performs all the activities needed for the effective completion of the customer's order, including manufacturing but also other processes such as:

- Product design with a high participation of customer through the usage of user friendly tools or exploiting the economies of interaction and relationship [17];
- Delivery service;
- After-sales activities (e.g. maintenance, end of life recovery).

Furthermore, the authors stressed the importance of networking all Mini-factories for sharing various types of information (i.e. customer requirements, solutions to problems in mini factory management), thus giving the opportunity to personnel to access to a huge and global knowledge. In this way the larger number of consumers involved was, the more the design products took on an evolutionary character. According to Zaeh & Wagner this distributed instantiation of Mini-factories can also have economic positive impact by reducing logistic costs and delivery times [18,19].

In the recent years, academics paid a greater attention to procedures for designing process of distributed manufacturing systems and its operations rather than to the proposal of distributed manufacturing model [20]. Matt & Rauch adopted an axiomatic approach for proposing a three levels framework for designing a franchise production system made of several "geographically distributed, changeable, scalable as well as replicable manufacturing units" [21]. Another example is represented by the study of Mourtzis & Doukas, who presented and holistic framework for configuring manufacturing networks able to effectively and efficiently deal with a mass customized production [22].

At the same time, since planning and scheduling production and logistics within a distributed system completely differs from a large-scale centralized manufacturing system, academics paid a greater attention to their optimization. In fact, traditional

scheduling methodologies like Genetic Algorithms, Fuzzy systems, Neural Networks, have run into difficulties in a decentralized manufacturing environment due to their centralized computational architecture [23]. Therefore, from the beginning of the new millennium several algorithms, mainly based on agent-theory, have been proposed for the maximization of the performances of these two operations in highly distributed manufacturing systems [24,25,26,27].

3.3 Collaborative Networked Organization

A further evolution of the distributed manufacturing systems has been presented in the last decade, when the concept of "distributed manufacturing network" overtook the enterprise boundaries, thus being included into collaborative networked organization (CNO) [28].

CNOs are modern organization structures those put together several actors, belonging to both the industrial and institutional world. In 2009 Camarinha, Matos et al. presented eleven different categories of CNOs on the basis of their scope, networking typology, players, and time and duration.

In particular, among the eleven categories of CNO proposed, two forms of inter-enterprise organization can be associated with the distributed manufacturing systems (Fig.3):

- "Virtual Enterprise", defined as a temporary collaboration of several enterprise, sharing information, competencies, facilities and resources. This concept could be particularly interesting for Small and medium size enterprises (SMEs), which usually have scarcity of skills and resources in comparison with large companies.
- Extended Enterprise (EE), a CNO where a focal enterprise "expands" its boundaries to all or some of its suppliers. To some extent, this model may be considered a particular case of the previous.

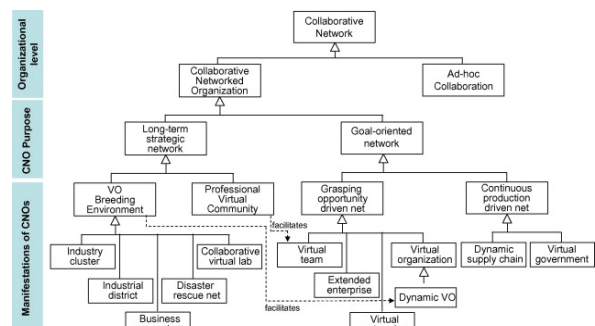


Figure 3 CNOs classification, Camarinha, Matos et al., 2009

Finally, two important models of distributed manufacturing networks have been presented within the classification proposed by Wiendahl & Lutz in 2002 [29] and then updated by Mourtzis and Doukas in 2012 [30]:

- Segmented Factory: segment is defined as "a modular in small, flexible, and decentralized structures that are self-responsible as well as market- and human-oriented" conceived for modular

products. Inside the company, the segments pursue different competitive strategies and each segment can have as customer or supplier other segment.

- Fractal Manufacturing: comprises units ('fractals') characterized by self-similarity, self-organization, and self-optimization features for coping with highly personalized orders. Moreover, this units are structured to be scalable, so that they are able to easily grow and shrink, and modular, thus easy to be separated, and restructured.

4. Conclusion

The state of the art discussed in the previous section reveals an evolution of the models associated to DMS denomination during the last three decades.

Initially, DMS models were a particular form of decentralized and modular production control system, where the distribution lay in the multiple controllers within the manufacturing systems.

In a second stage, DMS proposed were characterized by a geographical dispersion of the production systems. Indeed, in these models manufacturing operations of a single enterprise were carried out in several small-scale, flexible and reconfigurable units all around the world.

At a later stage, DMS comprised a fragmentation of the manufacturing activities among several enterprises in addition to the geographical distribution of the facilities, resulting in the so-called CNOs.

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